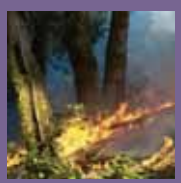
2 Integrated Science for Resource Management and Planning

Gone are the days when national parks were managed mostly for their scenic values, individual species of large animals, and various curiosities. Early park

management generally did not appreciate the interdependence of park natural resources or recognize how strongly they depend on the larger landscape. Today, heritage values of ecosystems have joined recreational and other values of parks in guiding stewardship. Prudent management of these values is based on science and strives to integrate multiple disciplines to give as complete a picture as possible of the condition and function of park natural resources. This trend to gain a more holistic understanding of park resources and

to view them in the ecological context of the modern landscape is reflected in the articles that follow. They describe numerous approaches to natural resource management that integrate various biological and physical science components in addition to land use history. They demonstrate the tremendous value of collaboration and teamwork,

the utility of synthesizing data from isolated studies, and the importance of focusing the right expertise on information gathering, analysis, and application to inform park management. Whether reporting work of the monitoring networks, cooperative ecosystem studies units, park staffs, or other entities, the articles suggest a level of sophistication—clearly beyond single-species management—that is appropriate and necessary for addressing challenges to preserving park



the complexity of contemporary natural resources.

"Americans are witnessing a paradigm shift in national park conservation and management.... Conservation strategies now recognize the need to include people as part of the system and to address cause, rather than symptoms, of system dysfunction by managing whole ecosystems, not just single species." — **William L. Halvorson and Gary E. Davis**

Determining risk of airborne contaminants to western national parks

By Tamara Blett

WHAT DOES *INTEGRATED SCIENCE* MEAN? In the National Park Service, it may mean an alphabet soup of "ists" and "ologists" who have come together for the Western Airborne Contaminants Assessment Project (WACAP). Biogeochemists, analytical chemists, toxicologists, limnologists, hydrologists, ecologists, plant physiologists, atmospheric scientists, fisheries pathologists, and fisheries endocrinologists are working as an integrated team to conduct environmental detective work on toxic compounds in eight western national parks. The Environmental Protection Agency, US Geological Survey, USDA Forest Service, Oregon State University, and University of Washington are working in partnership with the National Park Service (NPS) on this assessment.

An alphabet soup of "ists" and "ologists" … have come together … as an integrated team to conduct environmental detective work on toxic compounds in eight western national parks.

Specifically, this six-year project is designed to determine (1) if contaminants are present in western national parks, (2) where contaminants are accumulating (geographically and by elevation), (3) which contaminants pose a potential ecological threat, (4) which indicators appear to be the most useful to address contamination, and (5) the sources for contaminants measured at the national park sites. Very little information is available about the presence, distribution, and effects of contaminants in ecosystems in the western United States. Biomagnification, a process by which contaminants build up in ecosystems to a greater extent at higher levels of the food chain, is of particular concern in parks because of congressional mandates to protect parks unimpaired for future generations.

What are the challenges with integrating so many specialists into a cohesive project? Twice-yearly coordination meetings are held to keep everyone on track and to develop joint strategies for data sharing and collaborative analysis of results. A "science coordinator" for the project keeps the study on schedule and facilitates study design development, communication, reporting, and publication. A "logistics coordinator" deals with fieldwork planning for the team, database development, and quality assurance planning for all investigators in the group. A "project coordinator" provides program goals, communicates project milestones within the National Park Service, pulls together multisource funding, and deals with budgets and interagency agreements. Funding for the project is also integrated across a variety of sources: 23% from partners, 22% from the NPS Air Resources Division, 22% via the NPS Natural Resource Challenge, 21% through the NPS competitive Servicewide Comprehensive Call, 6% from park Recreational Fee Demonstration Program sources, 4% from NPS Inventory and Monitoring, and 2% from the NPS Water Resources Division.

Researchers from Mount Rainier National Park and the USGS sample snow, one of six ecological components being analyzed for contaminants as part of WACAP. The program enhances scientific understanding of the global transport of airborne contaminants and their associated effects on sensitive ecosystems in eight western national parks.

The information gathered as a part of this multiagency partnership project is of great value to the National Park Service because it manages an abundance of arctic and alpine ecosystems. This information is particularly important in these cold ecosystems where many types of toxic contaminants are more likely to condense out of the atmosphere and deposit.

Early results of this integrated team project show that some currently used chemicals, as well as others that are now banned in the United States, are present in high-elevation areas of western national parks. This is especially true in parks near agricultural areas. Agricultural pesticides, industrial by-products (PCBs), and flame-retardant coatings for fabric (PDBEs) have been detected in snow, vegetation, and fish in several of the parks where analysis has been completed. Final results of the study will be published in 2007. ■

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Integrated biological approach generates recovery of island foxes at Channel Islands

By Tim Coonan

IN ORDER TO PREVENT THE EXTINCTION of three subspecies of the endangered island fox (*Urocyon littoralis*) from San Miguel, Santa Cruz, and Santa Rosa Islands at Channel Islands National Park, California, the National Park Service brought together experts from a variety of biological disciplines. The integrated biological approach has resulted in a recovery milestone: the reestablishment of wild fox populations on San Miguel and Santa Rosa Islands and an increase in the Santa Cruz population to more than 200 foxes. Local zoo personnel helped develop husbandry methods (e.g., diet, pen design, and hygiene). Wildlife and zoo veterinarians, and wildlife pathologists and parasitologists developed a program of veterinary care in particular methods to mitigate the effects of disease and parasites. Genetic experts identified the relationships among captive foxes, established the pedigree, and together with captive breeding specialists designed a breeding program with guidelines for annual pairing. Bald eagle (*Haliaeetus leucocephalus*) and golden eagle (*Aquila chrysaetos*) experts developed removal methods for golden eagles, which had never bred on the islands before the 1990s. Experts in population modeling estimated the number of captive foxes that would need to be released annually to recover wild populations to viable levels within a decade. Working backward from these estimates, the recovery team determined the optimal size of the captive breeding program as 20 pairs on each island.

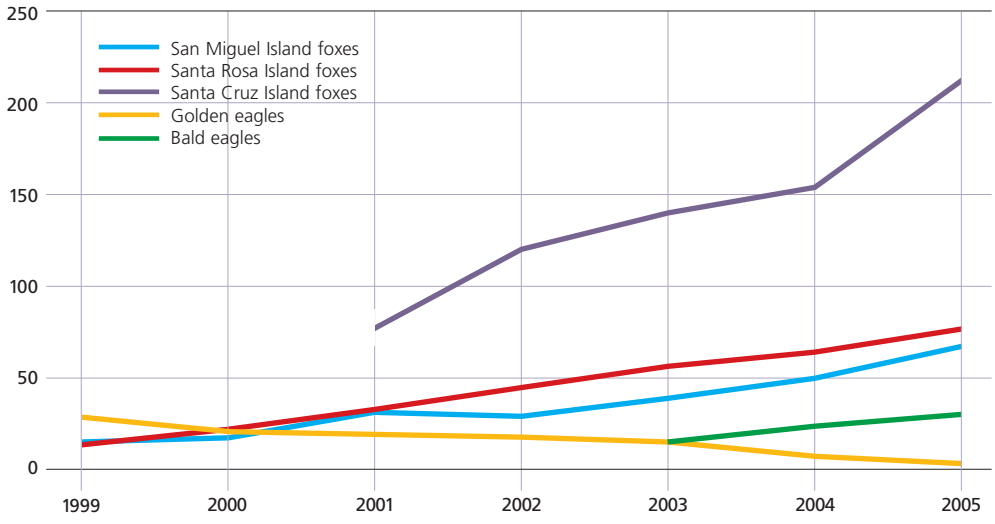
Demographic modeling provided a glimpse into the nature of interactions between golden eagles and their island prey species. From 1995 to 2000, island fox populations on San Miguel, Santa Cruz, and Santa Rosa Islands declined by as much as 95% because of predation by golden eagles. Modeling adequately supports the notion that island foxes would not be threatened with extinction today if feral pigs (*Sus scrofa*) had not been on Santa Cruz Island to support golden eagle breeding. In addition the absence of bald eagles, which were extirpated from the islands by 1960 because of organochlorine poisoning, facilitated golden eagle colonization of the islands. Bald eagles specialize in marine prey and do not take island foxes. Had bald eagles still been present in the latter half of the 20th century, they might have prevented the establishment of golden eagles, which take terrestrial vertebrate prey. Moreover, island fox decline allowed its only competitor, the endemic Santa Cruz Island spotted skunk (*Spilogale gracilis amphiala*), to increase to unprecedented population levels. Skunk abundance is once again beginning to tail off as island foxes increase in the wild.

Release of island foxes into the wild is a significant milestone for the island fox recovery program at Channel Islands National Park. However, release was realized only through an integrated biological approach that involved removal of feral pigs, relocation of golden eagles, and reintroduction of bald eagles to the northern islands. Six subspecies of island fox are distributed on the six largest of the Channel Islands, one subspecies per island.

Because predation by golden eagles is the only significant source of mortality for island foxes on the northern Channel Islands, eagle removal has been very effective at increasing fox survivorship and fostering population recovery. Since 1999, raptor biologists have captured 41 golden eagles from the northern Channel Islands and relocated them to mainland California. No relocated eagles have returned. The

RECOVERY OF ISLAND FOX 1999–2005, CHANNEL ISLANDS NATIONAL PARK

As wildlife biologists have removed feral pigs, relocated golden eagles, and reintroduced bald eagles, the number of endangered island foxes on San Miguel, Santa Rosa, and Santa Cruz Islands has increased, indicating they are on the road to recovery. Decline in the number of feral pigs is not included on the graph because recovery efforts did not record such data with any level of confidence; however, park staff estimates that 5,000 pigs inhabited the islands before removal efforts, with approximately 2,500 remaining at the end of 2005. Contractors will have removed the bulk of these remaining animals by summer 2006.



success of eagle removal is measured by the survival of wild island foxes on Santa Cruz Island. In 2005, annual survival of wild island foxes increased to well over 80%—the level determined by demographic modeling to be required for recovery.

From the beginning, the National Park Service championed an ecosystem approach to island fox recovery, which required the long-range actions of feral pig removal and bald eagle restoration and the short-term, species-specific actions of fox captive breeding and golden eagle removal. This integrated approach—which coordinated multiple agencies, academics, and nonprofits in what appeared to be a single-species management program by a single agency—garnered the necessary expertise for recovery of this heretofore poorly understood species. As of 2005 the total population of foxes on San Miguel was 67 (up from 15 in 1999), 77 on Santa Rosa (up from 14 in 2000), and 210 on Santa Cruz (up from 65 in 2000).

The Nature Conservancy, co-owner with the National Park Service of Santa Cruz Island, has proved an ideal neighbor, becoming a full partner in removal of pigs and golden eagles and in captive breeding of island foxes. The Nature Conservancy has contracted for pig removal, which began in spring 2005. The operation has quickly moved across the island and removal has begun on NPS property. Contractors removed about half the estimated 5,000 pigs in 2005 and will remove the bulk by summer 2006. At that time the island will be relatively free of pigs for the first time in more than 150 years.

The National Park Service is also cooperating with other agencies in an effort to reestablish bald eagles on the northern Channel Islands. Monies from the settlement of an environmental contamination case are funding annual release of up to 12 young bald eagles on Santa Cruz Island from 2002 to 2006. By the end of FY 2005, approximately 30 bald eagles remained on Santa Cruz Island from previous releases. Bald eagles mature at four or five years of age, so eagles from the first releases in 2002 may establish territories and attempt to breed in 2006.

Faced with the likely extinction of three island fox subspecies, the National Park Service began implementing recovery actions for island foxes on the northern Channel Islands in 1999. Although the Park Service has taken the lead in recovery actions for the three listed subspecies in the north, collaboration has characterized the effort from the beginning. A variety of project funding sources have supported fox recovery, including Natural Resource Preservation Program funding, 20% Recreational Fee Demonstration Program monies, and settlement funds from chemical contaminant cases. In FY 2005, Channel Islands National Park received a base increase of $477,000 from the Natural Resource Challenge for fox recovery. This base funding puts the recovery efforts, which are estimated to take as long as a decade, on firm financial ground for the duration of the program. ■

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Integrated management strategies used to protect cultural landscape of Bald Hills

By Terry Hofstra

DID YOU EVER THINK OF GRASSLAND as a cultural resource, something not unlike rock art or a historical dwelling? People shape the environment today, so it is in many ways unsurprising that Native Americans also influenced the landscape they inhabited for thousands of years. For example, Native Americans used fire to maintain prairie grasslands and oak woodlands in the Bald Hills of California. Today, modern fire suppression efforts and the invasion of nonnative plant species have resulted in the dramatic decline of these uncommon landscapes. Redwood National and State Parks is integrating both natural and cultural resource management strategies to protect the cultural landscape of the Bald Hills. In 2005 this effort resulted in the treatment of more than 2,000 acres (810 ha).

The elimination of Native American cultural use of fire and the control of wildfires allowed Douglas-fir (*Pseudotsuga menziesii*) trees to propagate and grow unchecked in the Bald Hills. These rapidly growing trees steadily encroached onto the prairies and oak woodlands, totally shading and eliminating native vegetation. For example, more than 85% of one prairie has been lost to Douglas-fir encroachment since 1829, when explorer Jedediah Smith recorded in his journal that his entourage camped there.

This landscape has also been assaulted by the intentional introduction of nonnative pasture grasses and other plant species. Two examples of harmful nonnative plants of special concern are tall oatgrass (*Arrhenatherum elatius*) and Scotch broom (*Cytisus scoparius*). Monitoring has shown that these plants have the ability to outcompete and suppress native plants. These invaders also have the potential to seriously impact the Bald Hills Roosevelt elk (*Cervus elaphus* subsp. *roosevelti*) population. A yearlong study of the diet of the elk, which was conducted by analyzing pellets, showed that the elk were not eating tall oatgrass. Likewise, large areas of Scotch broom, which forms dense brush fields up to more than 6 feet (1.8 m) tall, diminish habitat for grazing animals.

Redwood National and State Parks managers have implemented a combination of natural and cultural resource management strategies to combat these challenges and preserve native grasslands and oak woodlands and their dependent wildlife. By restoring fire to the Bald Hills, park managers are able to kill smaller Douglas-fir trees. Trees too large to be killed by prescribed fires are manually cut with chainsaws. In 2005 the park conducted prescribed burns on more than 2,000 acres (810 ha) of the Bald Hills and cut approximately 70 acres (28 ha) of large, fire-resistant Douglas-fir trees.

Park research has shown that prescribed burning in spring can control tall oatgrass and Scotch broom as well as other aggressive nonnative plants. However, this research also indicates that spring burning negatively affects the important native California oatgrass (*Danthonia californica*); therefore, burning has been restricted to the fall. Monitoring shows that tall oatgrass has been held in check to

The elimination of Native American cultural use of fire and modern fire suppression efforts have allowed Douglas-fir trees to steadily encroach onto the grassland prairies and oak woodlands of the Bald Hills. By restoring fire to the park, the National Park Service is able to kill smaller Douglas-fir trees in areas like Coyote Creek (pictured here). In 2005 this effort resulted in the treatment of more than 2,000 acres (810 ha).

Burns in ethnographically significant areas are conducted with sensitivity to the importance of these resources to the local Yurok Tribe. For example, individual large tanoak (*Lithocarpus densiflorus*) trees, which were tended and used for centuries by the Yurok as a source of acorns, are protected from fire.

date by this management program. However, the strategy for reducing Scotch broom involves removing the mature plants manually, followed by fall burning and subsequent control of seedlings and root sprouts.

Cultural resource protection activities have been undertaken in cooperation with the Yurok Tribe. Over the years, tribal members have provided important ethnographic information about the entire Bald Hills region. Yurok tribal staff has also conducted postfire monitoring of important archaeological and ethnographic resources through task agreements that are part of the tribe's self-governance compact with the National Park Service. Burns in ethnographically

The prairies and the surrounding oak woodlands are now managed as natural components of a cultural landscape, reflecting the complex interactions of human and nonhuman activities.

significant areas are conducted with sensitivity to the importance of these resources to local tribes. For example, measures are taken to protect individual large tanoak (*Lithocarpus densiflorus*) from fire. These same oak trees were tended for centuries by the Yurok, who used fire as a tool to maintain the health of the trees and thereby ensured successful acorn harvests. Additionally, historical structures and cultural landscape districts, archaeological districts, and ethnographic resources are being stabilized and protected.

Public education is also an important facet of the program. To increase public understanding of the use of fire and the need to protect this landscape, the park has invited the public to observe the prescribed burns and attend special educational field trips with park staff. The public has enjoyed the on-site discussions and the opportunity to closely but safely observe fire operations and understand management goals.

An integrated program to restore the prairies and oak woodlands has been evolving since the mid-1980s, when experimental work and pilot programs were first initiated. After the program took shape, more than 10 years of intensive management effort focused on restoring these important landscapes. The effort has paid off. The prairies and the surrounding oak woodlands are now managed as natural components of a cultural landscape, reflecting the complex interactions of human and nonhuman activities. As a result, these uncommon landscapes are beginning to make a comeback. ■

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Parks complete vital signs monitoring plans

By Pete Penoyer, Dean Tucker, Gary Rosenlieb, Barry Long, and Roy Irwin

MANY AMERICANS WOULD BE SURPRISED TO LEARN that 118 national park units that contain one or more bodies of water do not meet state water quality standards for one or more pollutants. For example, fecal-indicator bacteria impair recreational uses in 53 parks. Recognizing that solutions to water quality problems may require years of targeted effort, the National Park Service (NPS) is making progress toward understanding key water quality trends and conditions. In 2005 the first 12 networks completed their plans for water quality monitoring as part of a program of tracking resource conditions that began in 1999 with the inception of the Natural Resource Challenge initiative.

Water quality is just one of 12 broad "vital sign" components that have been selected for monitoring by the National Park Service. Each vital sign is a measurable indicator of change in the condition of key park resources and serves as an early-warning signal of possible long-term impairment of natural systems. To undertake Servicewide monitoring, the more than 270 natural resource park units have been organized into 32 monitoring networks. Now in their third year of planning and funding, the first 12 funded monitoring networks have successfully completed phase 3, the final stage, of monitoring plan development for water quality under the vital signs program. The process for developing monitoring plans was created in conjunction with the NPS Natural Resource Program Center. These 12 monitoring networks encompass 101 natural resource park units and represent over one-third of the more than 270 parks in 32 planned networks that are expected to develop monitoring plans.

Each network's water quality monitoring plan links the monitoring of individual parks to the federal-state regulatory framework established under the Clean Water Act. For example, the San Francisco Bay Area Network formulated its plan by first examining the beneficial uses of its water bodies as defined by the act and how these designations interact with state water quality standards. Common beneficial uses of water include recreation, aquatic life (including fisheries), public water supplies, and industrial and agricultural activities. A violation of water quality standards can occur when any narrative or numeric criterion is acutely exceeded or when designated uses are shown to be chronically affected adversely by human activities. The network then addresses the specific ecological water quality issues related to individual parks.

The first 12 networks to complete the water quality monitoring plans have made significant and highly useful contributions in sampling design, protocol development, and identification and selection of field and laboratory methods. Similarly, these networks have addressed many challenges related to data handling, analysis, and reporting procedures as they have finalized their planning efforts. The Cumberland Plateau Network, in particular, has demonstrated

In 2005, more than 100 national park units completed their plans for water quality monitoring. The Northeast Coastal and Barrier Network is working collaboratively with staff at the Assateague Island National Seashore, Maryland and Virginia, to develop an estuarine monitoring program that will address management issues of interest to both the park and the network. Pictured here is Sarah Sand, a seasonal park employee, collecting water quality data at Assateague Island National Seashore.

In 2005, NPS staff with the Greater Yellowstone Network participated in a training program at Bighorn Canyon National Recreation Area, Montana and Wyoming, to familiarize themselves with the latest multiparameter water quality monitoring instruments. Training on instrumentation is important because the technology changes rapidly. The NPS staff member pictured is measuring core water quality parameters for a cross section of the stream.

Marcus Johnson, resource management specialist at Shiloh National Military Park, Tennessee, collects a water sample from Owl Creek, which is on the park's western boundary. The sample will be analyzed for temperature, pH, specific conductance, dissolved oxygen, acid-neutralizing capacity, nitrate, and bacteria. Park staff works cooperatively with the Cumberland Piedmont Network to conduct water quality monitoring.

leadership in the acquisition of data and has already begun reporting to the NPS Water Resources Division new water quality information for its parks. These advances will save time and resources for the networks that will follow in their footsteps.

These examples highlight the focus and emphasis of the monitoring design process: monitoring must be driven by "measurable objectives," have an "identified target population," and provide sufficient accompanying metadata to be useful. Additionally, the questions formulated by the network must be resolvable using established USGS, EPA, or state protocols. Data must also be subject to rigorous quality assurance and quality control to ensure comparability with other data sources. With an eye to the future, the National Park Service has taken extensive measures not only to ensure that its data are comparable with those of other agencies, but also to encourage universities, watershed councils, and other volunteer groups conducting monitoring to document sufficient metadata.

Data capture, compilation, management, and sharing will be accomplished on a Servicewide basis using NPSTORET and NPS EDD (www.nature.nps.gov/water/infoanddata/index.htm). The data will then be funneled into the EPA's STORET National Warehouse (http://www.epa.gov/storet/dw_home.html). Storing data gathered from all 32 networks in the EPA database will assist parks, the Water Resources Division, and the Inventory and Monitoring Program in responding to issues requiring the Servicewide synthesis and analysis of water quality information, as required by the Government Performance and Results Act (GPRA).

Under the vital signs monitoring program, NPS water quality monitoring for the first time has a cohesive national structure. This structure is important because it will ensure that monitoring can help parks identify tangible management actions, achieve restoration and cleanup, and assess progress toward the attainment of NPS GPRA goals. Water quality monitoring plans represent the first step toward comprehensively addressing the water pollution and emerging contaminant issues that challenge national parks across the United States. ■

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Watershed assessments enhance cooperative coastal conservation

By Cliff McCreedy and Kristin Keteles

WATERSHED ASSESSMENTS THAT INTEGRATE the physical and biological sciences—including oceanography, water quality, marine and estuarine sciences, and geographic information systems (GIS)—are improving scientific understanding of coastal resources in the National Park System and revealing factors that may cause impairment. As of FY 2005, the NPS Water Resources Division (WRD) has initiated assessments of 41 ocean and Great Lakes parks through the Watershed Condition Assessment Program. Working with member universities of Cooperative Ecosystem Studies Units (CESUs), WRD staff plans to complete assessments of 52 ocean and Great Lakes parks. The Water Resources Division also coordinates closely with park managers and the NPS Inventory and Monitoring (I&M) networks to integrate coastal assessments into park and Servicewide databases and plans for monitoring vital signs, key indicators of ecological condition.

During the assessment process, scientists review and synthesize existing information to determine the condition of coastal park resources, including water quality, habitat status, invasive and feral species, extractive uses, and physical impacts from resource use and coastal development. Since FY 2004, assessments have incorporated geospatial information using GIS databases and maps, which facilitate evaluation of resource condition. In addition, GIS-based assessments are informational tools for reporting to strategic "land health" goals under the Government Performance and Results Act. Assessments cover all habitats, including upland, riparian, wetland, and coastal and marine areas.

Reports from coastal assessments identify information gaps that require further study and obstacles that hinder resource management efforts. For example, at Cumberland Island National Seashore, Georgia, investigators found low concentrations of dissolved oxygen in surface waters during summer months. This discovery has already resulted in increased attention by the State of Georgia concerning the potential for hypoxia in the Cumberland Sound and the need for additional monitoring. Hypoxia—critically low levels of dissolved oxygen that can harm populations of fish and invertebrates—is a condition linked to high levels of nutrients and algal blooms. Other potential threats to Cumberland Island's water resources are toxic compounds, metals, and invasive species.

The National Park Service needs to know the condition of coastal water resources in and around parks in order to address problems cooperatively.

Watersheds that drain into the coastal zone are dynamic hydrologic systems that create and sustain coastal ecosystems. Watershed

The Klamath River empties into the Pacific Ocean at Redwood National Park, California, where a coastal watershed condition assessment raises concerns about sediment runoff affecting park marine resources. The study is one of 41 assessments under way as of FY 2005 at ocean and Great Lakes units of the National Park System to evaluate resource conditions and identify information gaps that require further study to support resource management efforts.

health determines sediment flow, water quality, salinity, and other factors affecting aquatic ecosystems. With more than 55% of the US population now living within 60 miles (97 km) of a coast, this relatively high population density and the consumption of resources are taking their toll on coastal ecosystems. Coastal areas face many threats that could have dramatic impacts on the function and integrity of coastal park ecosystems, including:

- Coastal wetlands losses—more than 20,000 acres (8,100 ha) per year
- Water quality problems—harmful algal blooms, salinity changes, hypoxia, toxic pollutants, and eutrophication (nutrient enrichment leading to depletion of dissolved oxygen)
- Overfishing and recreational overuse
- Coastal development, unnatural shoreline change, and sediment flow alterations

The National Park System has more than 5,000 miles (8,045 km) of coast, including coral reefs, barrier islands, kelp forests, estuaries, and other ocean and Great Lakes resources. These coasts and the 74 national parks they contain attract more than 76 million visits each year. Hence the National Park Service needs to know the condition of coastal water resources in and around parks in order to address problems cooperatively with states, local entities, watershed councils, and park stakeholders.

By using common parameters and assessment methodologies, the Watershed Condition Assessment Program is collaborating with the US Environmental Protection Agency's National Coastal Assessment (NCA) Program. Park staffs, I&M networks, and the Water Resources Division are already using data and sampling protocols from the NCA Program. When assessments are complete for coastal parks in the vital signs networks, the NCA Program will provide information on regional conditions with which to elucidate and compare park conditions. Furthermore, these assessments are stimulating scholarly interest of coastal parks and increasing local partnerships with CESU universities. Though coastal parks are not immune to the problems plaguing the coastal zone, integrated watershed assessments are helping managers identify and tackle threats to coastal ecosystems. ■

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A watershed approach to coral reef management at War in the Pacific

By Dwayne Minton

INCREASINGLY, NATIONAL PARK and natural area managers and scientists are recognizing that ecosystem conservation must be conducted with a holistic perspective, looking not at artificially contrived compartments but at ecologically significant units, such as watersheds. Nowhere is this more apparent than in marine resource management, where threats often have an external terrestrial origin and their sources are difficult to identify and isolate. As a result, effective management of our coastal resources must start not at the low tide line but at the top of the mountains. Managers at War in the Pacific National Historical Park are taking this approach to coral reef conservation.

Effective management of our coastal resources must start not at the low tide line but at the top of the mountains.

Located on Guam, War in the Pacific protects more than 1,000 acres (405 ha) of Indo-Pacific coral reef, which is home to more than 3,500 species of marine plants and animals. Park reefs are threatened by numerous land-based environmental problems, including pollution, overharvest, and poorly regulated land development and recreational activities. One of the most severe impacts to park reefs is nearshore sedimentation. An estimated 27,558 tons (25,000 metric tons) of sediment—the equivalent of 20 dump truck loads per day—are deposited onto park reefs each year.

Sediments directly impact corals through burial, but also harm them by reducing water quality, particularly by diminishing light penetration. Without adequate light, reef-building, or hermatypic, corals will die. Park biologists have estimated that sediment loads on park reefs exceed scientifically quantified mortality thresholds for adult coral and also may be contributing to the low rates of new coral recruitment observed by park staff.

Land erosion is contributing up to 80% of the coastal sediments directly affecting park reefs. Though the problem is straightforward,

An NPS diver (left) fans a coral reef at War in the Pacific to reveal the sediments that have settled on and killed the corals at this site in the park. In the picture at right, corals in the lower left corner are dead; those in the upper right are partially dead.

A large wildfire burns through the savanna of the Asan watershed at War in the Pacific National Historical Park on Guam. The burned savannas, a major source of soil loss that contributes to sedimentation on the park's coral reefs (background), have been a focus of a watershed study of illegal wildland fires, erosion, and coral reef sedimentation.

finding a long-term, economically viable solution is a significant challenge. Erosion is not a simple process on Guam, where extreme environmental conditions, coupled with sociopolitical issues, have created an environmental problem that is destroying Guam's terrestrial and marine ecosystems. Frequent, intense storms can drop as much as 20 inches (50 cm) of rain in 24 hours; steep slopes accelerate the loss of highly erodible clay soils, and poorly planned development and frequent wildland arson along with loss of stabilizing vegetation contribute to accelerated soil loss. Park managers need sufficiently detailed information to better target their management actions to achieve the greatest environmental result.

To gain a better understanding of erosional processes contributing to coastal sedimentation, War in the Pacific undertook a two-year, multidisciplinary assessment of the park's watershed, which concluded in June 2005. With funding from the National Fish and Wildlife Foundation and the National Park Service and with help from cooperating soil scientists, botanists, and wildfire specialists, park coral reef biologists have studied the complex interaction of fire and vegetation structure in upland erosion and coastal sedimentation. The results of this work have been used to develop a strategy for reducing coral reef sedimentation through erosion mitigation.

On Guam, wildfire is not a natural process, and illegal wildland arson contributes significantly to erosion. From June 2003 to June 2005, four wildfires burned approximately 3% of the park watershed, resulting in 3,197 tons (2,900 metric tons) of lost soil. Wildfires were found to promote invasive grasses, increasing fire frequency and intensity. As fragile topsoils are lost, underlying, inhospitable clays are exposed. These areas, known locally as badlands, are incapable of supporting vegetation, and while they cover only about 5% of the watershed, they account for up to 6,063 tons (5,500 metric tons, or 22% of the total) of soil loss per year.

Elaborate and costly engineering structures such as sediment basins have been proposed to reduce sediment flushing onto park reefs. These structures, though potentially successful, are expensive, do not address the ultimate problem, and require constant and costly maintenance to be effective. The park study suggests that a better long-term management option is to eliminate illegal wildfires and restore badland areas, potentially reducing soil loss and coastal sedimentation by 34% to a level below thresholds of coral mortality.

Recognizing that it has limited resources to achieve these objectives, the park has maintained close partnerships with territorial agencies and nongovernmental organizations. Using these partnerships, park staff hopes to develop a program of culturally sensitive education and community enforcement that will eliminate illegal wildland arson within the park watershed. The park is also working closely with territorial foresters to develop viable badland restoration techniques to restore these problematic areas. ■

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Scientific partnerships evaluate coral reef health at Virgin Islands monuments

By Cliff McCreedy

INTERAGENCY PARTNERSHIPS PROVED INVALUABLE in 2005 as the National Park Service sharpened its scientific focus on the health of coral reefs in "no-take" reserves in two Virgin Islands national monuments. Now that fishing and anchoring are prohibited in these reserves, the National Park Service (NPS) must evaluate how fish, shellfish, and corals are responding to this protection.

Coral reefs are the most biologically diverse marine ecosystems on the planet. On a healthy coral reef, several thousand species interact in complex, interdependent relationships that maintain the ecological balance among fish, invertebrates, and marine plants. Overfishing, anchor damage, pollution, and rising sea-surface temperatures disrupt this delicate balance. The National Park System includes more than 276,000 acres (111,780 ha) of coral reefs in Florida, Hawaii, the US Virgin Islands, Guam, and American Samoa. The most recent additions to the park system are the new Virgin Islands Coral Reef National Monument and more than 18,000 acres (7,290 ha) added to Buck Island Reef National Monument, both established in 2001 by presidential proclamation to restore and maintain coral reef ecosystems.

In the Virgin Islands parks, scientific partnerships and interagency collaboration greatly enhance the parks' capacity to evaluate the extent and condition of coral reef resources. The ecological complexity and variability of coral reefs make evaluation a difficult task that requires an extremely rigorous approach. Several partners, including the NPS Natural Resource Preservation Program, NPS South Florida/Caribbean Inventory and Monitoring Network, individual park staffs, National Oceanic and Atmospheric Administration (NOAA), and US Geological Survey (USGS), work together to develop habitat maps and biological data for park managers.

In the Virgin Islands parks, scientific partnerships and interagency collaboration greatly enhance the parks' capacity to evaluate the extent and condition of coral reef resources.

Staff from Buck Island Reef National Monument and scientists with the NOAA National Center for Coastal and Ocean Science Biogeography Program have been mapping submerged habitats and documenting marine species in the expanded Buck Island Reef area using aerial photography, satellite imagery, underwater video cameras, and side-scan sonar on remotely operated vehicles towed by the research vessel *Nancy Foster*. Detailed topographic imagery from the USGS Coastal and Marine Geology Program enhances the maps, which are obtained by aircraft scanning the bottom of the sea with a laser altimeter. The end result is detailed seafloor maps that enable resource managers to identify the extent and variation of different types of coral habitats. Local scientists from the US Virgin Islands Department of Planning and Natural Resources participated in the *Nancy Foster* missions. These efforts continued in 2005 at Buck Island Reef and Virgin Islands Coral Reef National Monuments with funding from the NPS Natural Resource Preservation Program and Geologic Resources Division.

These advanced technological tools provide only part of the picture. To identify marine species using these reefs, divers from the parks, the South Florida/Caribbean Inventory and Monitoring Network, and NOAA make detailed visual surveys of fish and shellfish and measure coral reef habitat. Biologists with the USGS and the National Park Service conduct coral monitoring at both Virgin Islands National Park on St. John and Buck Island Reef National Monument to track coral disease, bleaching and mortality, and long-term coral health.

"These national monuments and the Virgin Islands National Park are highly popular for their beautiful landscapes above and below water," says Craig Manson, Assistant Secretary for Fish and Wildlife and Parks, in 2004. Manson cochairs the US Coral Reef Task Force. "They are mainstays of the tourism economy of the US Virgin Islands. They protect sensitive coral reef areas enjoyed by hundreds of thousands of visitors every year. That is why we must do everything we can to ensure their success." ■

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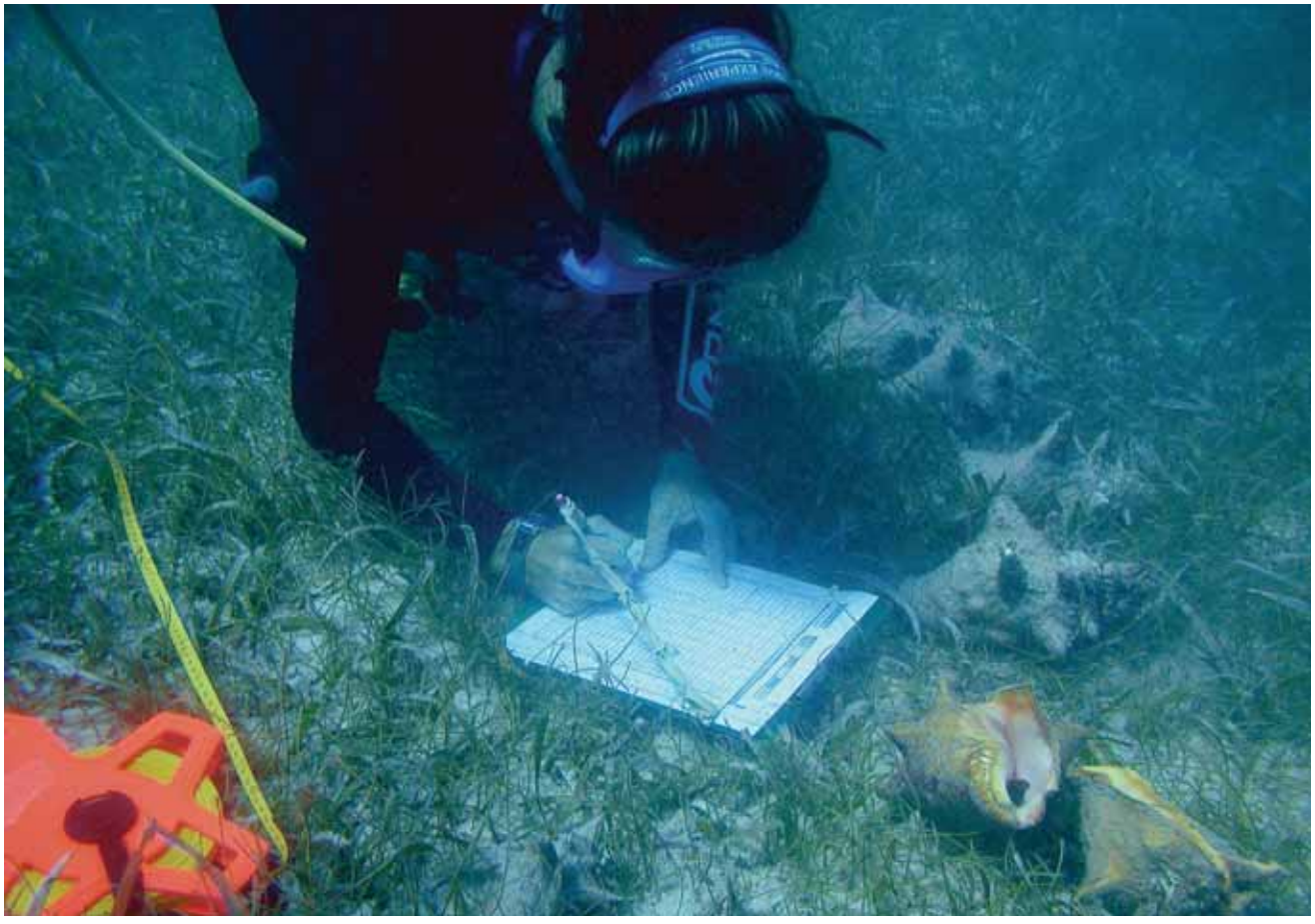
(Facing page, top) Scientists from the National Park Service and other agencies are collaborating to assess fish and coral habitats in a recently established "no-take" marine reserve at Buck Island Reef National Monument, St. Croix, US Virgin Islands, where blue tangs (*Acanthurus coeruleus*), doctorfish (*Acanthurus chirugus*), and ocean surgeonfish (*Acanthurus bahianus*) school.

(Facing page, bottom) An NPS science diver measures the size of queen conchs (*Strombus gigas*) at Buck Island Reef National Monument to document the status and potential recovery of this commercially exploited shellfish in a new "no-take" marine reserve.



Learning from past research: An aquatic synthesis for Great Lakes Network parks

By Brenda Moraska Lafrancois and Jay Glase

GREAT LAKES AND BIG RIVERS feature prominently on maps of the upper Midwest, and some of the region's finest aquatic resources are protected as units of the National Park System. The Great Lakes Network of parks consists of two water-based national parks, two riverine parks, four national lakeshores, and a national monument on Lake Superior. In July 2005 the NPS Water Resources Division published an aquatic synthesis technical report that will help the Great Lakes Network develop monitoring strategies, support planning activities at parks, and advance new Watershed Condition Assessment Program projects.

Researchers in these parks have explored chemical and hydrologic attributes of the area's diverse aquatic habitats, studied biota ranging from microbes to moose, and addressed a variety of pressing water resource concerns. To synthesize the wealth of existing information and identify aquatic resource issues, themes, and remaining information needs, the Great Lakes Network and the Midwest Regional Office supported a wide-ranging review of past aquatic studies from 2003 to 2005.

In 2003, regional aquatic professionals collected relevant materials from each of the nine parks and the regional office and discussed aquatic research and monitoring concerns with park and network staff. Baseline Water Quality Data Inventory and Analysis reports, prepared for each park by the Water Resources Division in the 1990s, were also reviewed. In addition to these internal searches, online literature searches were conducted using park names as key words, and publications from state natural resource agencies and the US Geological Survey were reviewed.

[The] … report … will help the Great Lakes Network develop monitoring strategies, support planning activities at parks, and advance new Watershed Condition Assessment Program projects.

Studies addressing any aquatic or semi-aquatic organism, habitat, or process qualified for inclusion in the synthesis, and more than 600 studies fit these criteria. General categories of resource topics emerged during an initial review, including water quality, biology and ecology, fish, aquatic wildlife, amphibians and reptiles, wetlands and aquatic vegetation, contaminants, hydrology, groundwater, and physical structure and processes. Studies were placed into one of these categories, and key information from each study (author, publication date, methods, results, and conclusions) was recorded in a summary table. This table became a useful review template for the synthesis.

To serve both park and network needs, two levels of summary and synthesis were performed: park-specific and network-wide. For each park-specific chapter, maps of aquatic resources, basic water resource statistics, and a general summary of previous water studies were provided. Dominant research themes, strengths, and remaining needs were identified, along with specific considerations for future aquatic research and monitoring. The network-wide synthesis followed a similar structure, with an emphasis on common information needs among parks and an exploration of future multipark research possibilities.

Floats mark fish traps at Isle Royale National Park, Michigan, during a recent nearshore fishery survey conducted by the US Geological Survey for the National Park Service. This survey developed information on seldom-studied species in Great Lake Network parks and is one of the many types of research and monitoring efforts referenced in the aquatic synthesis report.

Brook trout restoration efforts are ongoing in several areas around Lake Superior, including three units of the National Park System. Information from this survey and others was included in the fisheries sections of the Great Lakes Network aquatic synthesis report.

Research considerations contained in the document are expected to stimulate development of new research proposals and help communicate park needs to cooperators. Finally, given the breadth of literature included, the synthesis represents a common reference document to be consulted by park managers and shared with interested partners into the future. ■

A copy of the complete synthesis report is available at http://www1.nature.nps.gov/im/units/glkn/reports.htm.

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Development pressures prompt integration of science and planning to enhance stormwater management in the Cuyahoga Valley

By Kevin L. Skerl, Jeff Winstel, and Thomas E. Ross

IN 2005, TO COMBAT IMPACTS of increased development on watershed health, park managers at Cuyahoga Valley National Park began urging better stormwater management through environmentally sound community planning. Increased development in areas surrounding the park (i.e., more roadways, buildings, parking lots) has decreased the amount of open land available to absorb surface water. This increased watershed "imperviousness" has, in turn, led to increased runoff and flooding in the area.

Knowing that development outside the park will likely continue ..., efforts were focused on ensuring that future development is sensitive to environmental concerns.

The park protects 33,000 acres (13,365 ha) between the cities of Cleveland and Akron, Ohio. It is home to 22 miles (35 km) of the Cuyahoga River and more than 190 miles (306 km) of tributaries (with most watersheds extending out beyond park boundaries). At an ever-increasing rate, the 15 communities surrounding the park have experienced considerable residential and commercial development.

In 2003–2004, the park experienced major flooding, which caused more than $3 million in damages to park infrastructure, recreational facilities, and historical and cultural resources. Many local communities also experienced severe economic impacts from the floods. Although these floods were due to unusually heavy rain, even typical storms are causing floods.

As watershed imperviousness escalates, surface water runoff increases and stream channel erosion and sedimentation occur. These changes result in increased flood frequency and adverse impacts to water quality, habitat structure, and biodiversity. Stormwater management, always an important planning issue, became a priority concern after the floods. Park managers embraced the issue as a unifying theme to engage and educate local communities. Knowing that development outside the park will likely continue despite these adverse effects, efforts were focused on ensuring that future development is sensitive to environmental concerns.

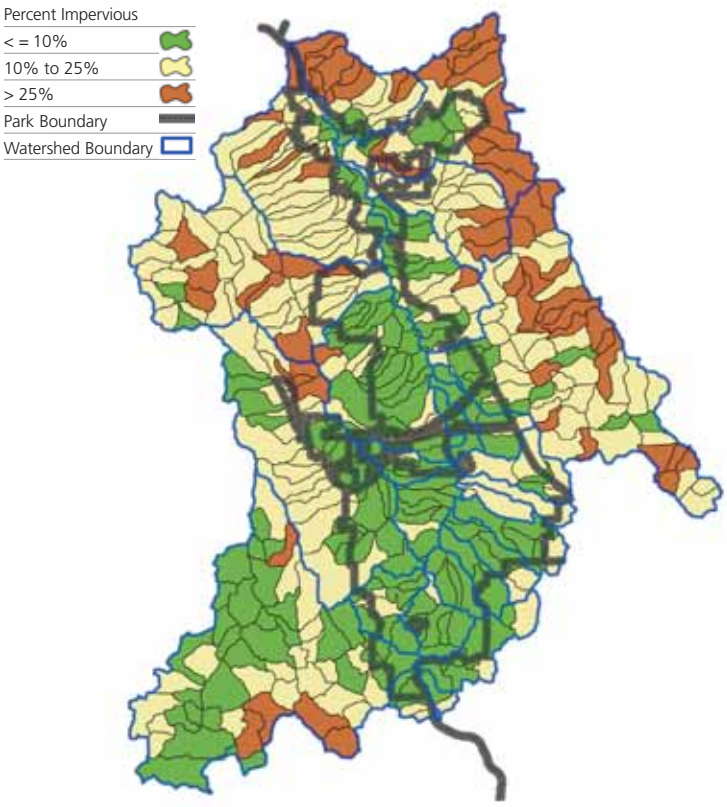
Appropriate development zoning and local ordinances can reduce the impacts of development on watersheds. Such measures include requiring significant open green space (greater than 40%), riparian and wetland setbacks, distributed on-site stormwater management, and protection of steep slopes and sensitive areas. Unfortunately, park managers lacked a comprehensive understanding of existing community zoning regulations. This limited their ability to carry out effective outreach on this issue.

To address this problem an interdisciplinary team was assembled, consisting of an ecologist, a park planner, and a visiting deputy superintendent (on a USDA Graduate School Executive Leadership Program developmental assignment). This team worked together to

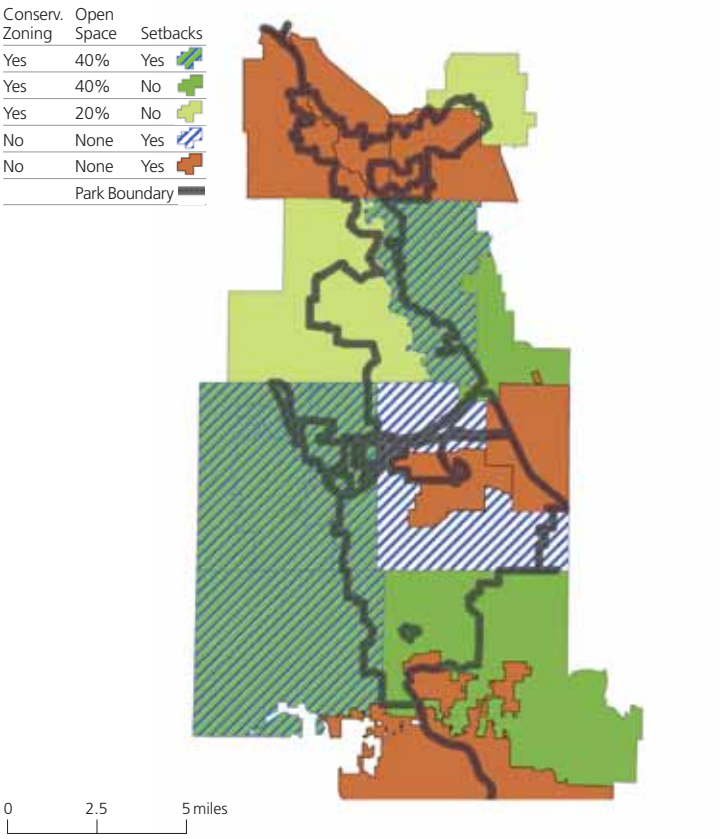
Flood damage from unusually heavy rainfall in July 2003 leaves the railroad tracks of the Cuyahoga Valley Scenic Railroad crossing the open air. However, through increasing development in surrounding communities and the subsequent decrease in land available to absorb runoff, even moderate stormwater can now cause flooding in and around Cuyahoga Valley National Park.

As watershed imperviousness increases, damage to park infrastructure also increases.

IMPERVIOUSNESS: SUBBASINS



LOCAL ZONING AND ORDINANCES



To identify high-priority areas to target through public planning, staff at Cuyahoga Valley National Park assessed (left) imperviousness at the subbasin scale and (right) local zoning and setback ordinances in the national park. Healthy subbasins (in green, left map) that extend beyond the park are priorities for protection, especially those in communities lacking conservation zoning and setback ordinances (in brown, right map).

assess watershed imperviousness and review local zoning and setback ordinances.

Scientific literature has established a set of thresholds indicating that watersheds are relatively healthy until they surpass 10% imperviousness. After that point there is a steady decline in quality. (Watersheds at or above 25% imperviousness are considered to be in poor condition.)

Using GIS-based tools and analysis, the team found that 14 of 27 watersheds (52%), most largely contained within the park, remain in good condition (less than 10% imperviousness). However, these watersheds typically extend beyond the park boundary and thus face development pressures. Analysis revealed that even within impacted and poor-quality watersheds, many subbasins (37%) remain healthy. Healthy watersheds and subbasins were considered critical areas for protection.

The review of local zoning regulations and ordinances revealed that only 8 of the 15 communities (53%) have some type of conservation development zoning regulation in their code. Only 6 of the 15 communities (40%) have riparian setback ordinances. Some communities that lack conservation zoning or setback ordinances are located in healthy watersheds. These communities were identified as priorities for outreach.

This team effort has resulted in increased local community and media interest. Park presentations to local planning and zoning commissions, stormwater management officials, and community organizations have effected positive change on several projects. The park is now increasingly asked to comment on development proposals and to participate in community planning.

Information is also now being shared with several local communities that are revising their zoning codes. Community-specific reports that encourage zoning updates and maps that depict possible changes in imperviousness from various development scenarios are being generated. Such buildout scenarios are facilitating effective communication of the importance of watershed stewardship.

All in all, these efforts demonstrate that by integrating science-based watershed assessments with an understanding of local zoning, national parks facing similar external development pressures may better protect downstream park resources by influencing change beyond their boundaries. ■

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Midwestern national parks use best available science to "mimic" natural conditions in bison and elk management

By Daniel S. Licht and Joshua J. Millspaugh

A LARGE, AGITATED BISON is prodded down a narrow chute by National Park Service (NPS) employees at Badlands National Park. At the end of the line, gates drop in front of and behind the animal, pinching it tightly. Resource managers then decide the animal's fate: release it back into the park or remove it from the herd.

Two hundred years earlier at the same site, a pack of wolves looked down upon another herd, assessing each animal for weakness. The old and the young were especially vulnerable. The predators made a decision and an animal was killed, shaping the demographics of the herd.

Wolves are now absent from Badlands, Wind Cave, and Theodore Roosevelt National Parks. However, these three parks in South and North Dakota support fenced-in bison herds; the latter two are also home to elk. To meet carrying capacity objectives, such as preserving floral diversity, park staffs periodically cull surplus bison and elk. Until recently this management practice was done with little consideration of natural herd demographics.

National Park Service policies direct managers to conserve not only native species but also natural patterns and processes, such as maintaining natural age and sex structures among ungulate herds. When large predators are absent from an ecosystem and cannot be restored for ecological, political, or logistical reasons, management must intervene, ideally in a way that mimics nature. Such activities require a thorough understanding of natural conditions.

To gain this understanding these parks and the Midwest Regional Office partnered with Dr. Josh Millspaugh of the University of Missouri to reconstruct natural bison and elk demographics. A regional block grant of $16,926 from the Natural Resource Preservation Program funded the study through the Great Plains Cooperative Ecosystem Studies Unit (CESU). Millspaugh and his graduate-level class conducted the research. The collaboration was an excellent example of how the CESU can obtain exceptional information for park managers at reduced cost and give students at partner universities a real-world problem to solve.

The class used an interdisciplinary approach to reconstruct herd demographics in the presence of (1) only predators, (2) Native Americans before arrival of the horse, and (3) Native Americans during the horse-dominated period. Students reviewed historical literature for insight into ungulate and predator demographics and also examined anthropological information for evidence of human densities, caloric needs, and harvest patterns. Data from the Vore buffalo jump, a sinkhole in Wyoming where Native Americans stampeded bison, were especially useful in reconstructing the sex and age structure of harvested bison. The students applied soils information and GIS technology to estimate historical forage availability in the parks and the likely ungulate densities that could be supported. They also used predator-prey data and theory to estimate the likely take of various age and sex classes. Because wolves

Bison graze peacefully in Badlands National Park where they are periodically culled to meet range objectives. Animals removed from the park are live-transported to help start herds elsewhere, for example on Native American reservations. Park managers are using scientific information from a recent study to develop management plans that would help them mimic natural patterns of age and sex ratios of bison and elk herds at three Great Plains parks where wolves are absent.

Elk herds at Wind Cave and Theodore Roosevelt National Parks may have an unnaturally high proportion of mature bulls, according to a recent study. A high proportion of breeding-age male elk can reduce the size of harems, potentially leading to increased strife. Conservation of natural herd demographics is one of many factors considered when selecting animals for removal.

are absent from the Great Plains, the researchers relied on information from other ecosystems, such as Yellowstone National Park, demonstrating how wolf restoration there has implications beyond that park. Finally, they compiled existing demographic information from the three parks to develop a user-friendly computer model.

Final study results, delivered in 2005, were timely because the parks are in various stages of developing bison and elk management plans. The computer model is particularly useful, allowing the parks to evaluate and compare various culling scenarios (e.g., yearly versus periodic). Of course the management plans will need to reconcile NPS policies of naturalness with herd genetics and disease concerns, vegetation objectives, and fiscal, logistical, and political realities.

Managing wildlife in a way that mimics natural conditions and processes is an important goal of resource stewardship of national parks. This study of bison and elk demographics at Badlands, Wind Cave, and Theodore Roosevelt National Parks gives managers good information to consider for culling actions. ■

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The Ozark hellbender: An indicator of unseen change at Ozark National Scenic Riverways

By Jessica Luraas

OZARK NATIONAL SCENIC RIVERWAYS, located in southern Missouri, supports one of the most pristine rivers in the country, the Current River. It also supports a very unusual species, the Ozark hellbender (*Cryptobranchus alleganiensis bishopi*). The hellbender is a large, strictly aquatic salamander that can reach a length of 2 feet (61 cm) and live for 30 years. It has very specific habitat requirements, including cool, spring-fed waters with high oxygen levels and large, flat rocks for refuge. Known populations of the Ozark hellbender are found in only four watersheds in the hills of southern Missouri and northern Arkansas. To the casual observer who sees the clear waters of the Current River, the Ozark hellbender appears to have ideal habitat and water quality for a healthy population. Unfortunately, this is not the case. The species has rapidly declined throughout its range, 77% over the last 20 years. This decline has prompted its listing as a candidate endangered species under the Endangered Species Act. In 2005, with funding from the Natural Resource Challenge, the Heartland Network—part of the national Inventory and Monitoring Program—contracted Dr. Chris Phillips, a herpetologist with the Illinois Natural History Survey, to conduct a parkwide inventory of hellbenders, map all suitable habitat, and develop a long-term monitoring protocol.

At the current rate of decline, Ozark hellbenders could disappear in the next 20 years in parts of their range.

Along with the rapid population decline over the last 20 years, previous population inventories in Missouri and Arkansas have found few juvenile hellbenders, indicating a lack of consistent reproduction that may be caused by increased levels of pesticides, nutrients, and endocrine disrupters that affect fertility and hatching. In recent years, tumors, lesions, missing or deformed limbs, and other abnormalities have become more common. Exact causes for population decline are unknown and more research is needed to definitively determine them, but hellbender experts suggest the causes may relate to changes in the Current River watershed (outside park boundaries). These include increased sediment and nutrient-loaded runoff, removal of large flat rocks from streambeds, gravel mining, and other stream channel alterations. Other causes could be the presence of nonnative trout that prey upon juvenile hellbenders, illegal collection for pet trade, and indiscriminate killing by anglers. At the current rate of decline, Ozark hellbenders could disappear in the next 20 years in parts of their range.

Phillips surveyed more than 70 miles (113 km) of river in summer 2005 and found only five hellbenders at four locations. For perspective on the drastic reduction of population density, in the 1970s researchers located 300 to 500 hellbenders per kilometer (0.6 mi) of streambed in the North Fork of the White River, a watershed adjacent to the Current River. The inventory and a complete map of all suitable habitat within the park will be completed in summer 2006. Data will be used to

develop a statistically robust sampling design and long-term monitoring protocol. The protocol will be shared with other agencies monitoring Ozark hellbender populations so that similar methodologies can be applied throughout the hellbender's range, allowing for more integrated and comparable data among watersheds over time.

Efforts to save the remaining Ozark hellbenders are dependent on first understanding the population status and developing statistically sound monitoring protocols to track changes over time. The National Park Service is playing an active role as part of the Hellbender Working Group, an interagency effort to develop a recovery plan in conjunction with state agencies in Missouri and Arkansas, the US Fish and Wildlife Service, several area universities, and the St. Louis Zoo. The park holds high hopes that the combination of monitoring information and efforts of this conservation partnership will lead to effective protection of this sensitive species. ■

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A healthy Ozark hellbender has a life span of up to 30 years and does not reproduce until five to seven years of age. Those factors, combined with the hellbender's specific habitat demands, make this species a key indicator of broader changes in water quality, habitat, and land use in the surrounding area.

Hellbenders require cool, spring-fed waters like the Current River in the Missouri Ozarks.

Research to identify sources of nitrogen pollution at Rocky Mountain National Park

By Elizabeth Waddell and Terry Terrell

MORE THAN 20 YEARS OF RESEARCH on air and water quality in Rocky Mountain National Park by scientists with the US Geological Survey, University of Colorado, Colorado State University, and other scientists has identified nitrogen deposition as a growing threat to park resources. A comprehensive new study begun in 2005 integrates chemistry, physics, meteorology, and mathematical modeling to determine the sources and fates of nitrogenous emissions affecting the park. Air samples are collected in a variety of sampling devices spread out over a geographically extensive area and then analyzed for a chemical "fingerprint" that uniquely identifies the sources of various types of nitrogen pollution. Once managers know the sources of the pollution most affecting the park, this information can be shared with regulatory agencies and the public to help craft a strategy to manage this growing problem. The study is the result of a unique cooperative effort of the Colorado Department of Public Health and the Environment, NPS Air Resources Division, and Rocky Mountain National Park.

Nitrogen-bearing emissions such as oxides of nitrogen (NO_x) and ammonia (NH_3) play key roles in the formation of ozone, in contributions to visibility degradation, and in atmospheric deposition of reactive chemicals that are altering the natural ecosystems of Rocky Mountain National Park. Effects include changes in aquatic plant species composition (diatoms), surface water nitrogen saturation, and changes to soil and tree chemistry. Results of models projecting current annual increases in nitrogen deposition into the future suggest not only a continued decline in air quality and ecosystem function but also episodic fish kills within 20 years unless the increasing rate of nitrogen deposition is controlled.

Effects [of nitrogen deposition] include changes in aquatic plant species composition …, surface water nitrogen saturation, and changes to soil and tree chemistry.

The first step to reducing deposition is to determine specifically where the NO_x and NH_3 emissions originate. Agriculture is the largest source of ammonia, which comes from both fertilizer use and animal waste. Motor vehicles, fossil fuel–fired power plants, and oil and gas production are all major sources of NO_x. But what is not known is whether the impacts measured in the park are due to pollution from the urban communities just east of the park or from sources throughout Colorado, or if a significant amount of the pollution entering the park is transported long distances from places like California or the Midwest.

Whose NO_x falls on Rocky Mountain National Park? Park managers hope to begin to answer that question in 2006 when initial results from the study become available. ■

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In contrast to the west side of Rocky Mountain National Park, Engelmann spruce forests east of the Continental Divide exhibit higher nitrogen content and chemical imbalances in both soils and trees. Park managers are concerned about nitrogen deposition at the park because of various ecological effects associated with it. For example, research in forests in other parts of the country has shown that excess nitrogen may make trees less resistant to insect infestation, cold, and drought.

Researchers at Rocky Mountain National Park are deploying a variety of sophisticated air quality monitoring equipment to accurately measure different types of air pollution reaching the park. These "mini-vols" will determine the geographic distribution of that air pollution.

Precipitation and fire effects on flowering of a threatened prairie orchid

By Gary D. Willson, F. Adnan Akyuz, and Manda J. Page

PIPESTONE NATIONAL MONUMENT, a small cultural park in southwestern Minnesota, includes areas of remnant tallgrass prairie that are habitat for a small population of the threatened western prairie fringed orchid (*Platanthera praeclara* Sheviak & Bowles), a perennial plant with a lifespan of less than 10 years. Managers at the park conduct prescribed burns in the tallgrass prairie in spring to control smooth brome (*Bromus inermis* Leyss.) and other invasive cool-season grasses. In the early 1990s, managers became concerned that the prescribed burns might have a negative effect on prairie forbs, including the threatened orchid. In response they initiated a monitoring program in 1995 to track the status of the orchid population over time. Monitoring included an annual census of flowering plants in mid-July. Scientists with the USGS Biological Resources Discipline and the Prairie Cluster Long-term Monitoring Program (now part of the Heartland Inventory and Monitoring Network) then used these data in a study undertaken to provide management recommendations for the use of prescribed fire in orchid habitat that would help conserve the orchid population. Results of the study were accepted in December 2005 for publication in spring 2006.

The monitoring record over 10 years revealed that the number of orchid plants that flowered varied considerably, ranging from 0 to 221. The prairie was burned in 1997 and 2002 and the number of orchids that flowered in those two years also fluctuated dramatically: 3 and 124 plants, respectively. Flowering, it seemed, must respond to factors

The flowering of the western prairie fringed orchid (above) can be impacted by prescribed burning (left), depending on precipitation before and after burning. The plant produces buds in August for flowering the following July. Results of a recent study will help managers at Pipestone National Monument in Minnesota to plan prescribed burns in a manner that is sensitive to the conservation of this threatened plant species.

Study finds introduced black locust tree harbors nonnative understory at Cape Cod

By Betsy Von Holle

A THREE-YEAR STUDY at Cape Cod National Seashore (Massachusetts) has found that some invasive species, in this case black locust (*Robinia pseudoacacia*), appear to support the presence of other nonnative species. Black locust, a nitrogen-fixing tree native to the central Appalachian and Ozark Mountains, is considered to be one of the top 100 worldwide woody plant invaders. It reproduces aggressively in areas with full sun, well-drained soil, and little competition. Black locust spreads by root suckering and stump sprouting to form groves of trees interconnected by a common fibrous root system. This study was initiated to determine the impact of introduced black locust on an upland coastal ecosystem and to estimate the spread of this species at Cape Cod National Seashore.

Betsy Von Holle conducted the research as part of the postdoctoral National Park Ecological Research Fellow program, coordinated by the National Park Service, National Park Foundation, and Ecological Society of America and funded by the Andrew W. Mellon Foundation. Additional support came from the National Science Foundation and the National Park Service. Von Holle is sponsored by the Harvard Forest, a long-term ecological research site that is part of Harvard University.

In field research conducted in summer 2003 through 2005, Von Holle and her students in the Harvard Forest Summer Program studied the introduced nitrogen-fixing black locust tree and its understory. They found that black locust had an average of 10 times the number of nonnative species under its canopy as did native species, primarily pitch pine

other than burning. Previous research on this orchid suggested that precipitation in combination with burning is the primary cause of variation in numbers of flowering plants. Fortunately, Pipestone has a National Weather Service Reporting Station that has kept records since 1950 and thus offered a tremendous opportunity to further investigate precipitation and fire effects on flowering.

Using the orchid monitoring data and precipitation history, the researchers compared the counts of flowering plants from the nonburn years with precipitation totals during six growth stages of the orchid. They found that about 77% of the annual variation in the number of flowering plants was explained by precipitation in two

Managers became concerned that the prescribed burns might have a negative effect on prairie forbs, including the threatened [western prairie fringed] orchid.

stages of the orchid's annual life cycle before flowering: during bud development in the previous August, and during dormancy in the previous winter (October through March). Results suggested that above-normal precipitation in August stimulates plants to develop buds capable of flowering the next summer, whereas above-normal precipitation in the previous dormant season saturates the soil, stressing or killing plants and reducing flowering.

The investigators applied a model developed from nonburn years to precipitation records from the two burn years that occurred during the study and compared them with the counts of flowering plants from those years. Results were inconsistent between years but suggested that lack of precipitation following a burn could reduce flowering depending on the amount of the precipitation deficit. Therefore, the resulting recommendations for protecting the orchids when prescribed burning is planned are based on precipitation history and forecast.

For example, if the previous late summer was wet and the winter dry (high number of flowers predicted), the spring precipitation forecast is the deciding factor when considering burning. Fire in a dry spring in such a year would further dry the soil, possibly causing flower buds to abort. But when a wet spring is forecast in such a year, burning would do no harm if it occurred in early to mid-May, before the plants were large enough to be damaged by the fire. It might even be beneficial by reducing competition from exotic cool-season plants.

If, however, the previous late summer was dry and the winter wet (low number of flowers predicted), the coming summer's flowering would be minimal, and burning in either a dry or wet spring would not impact flowering. Nonetheless, burning in early to mid-May, before the orchids are fully emerged, is recommended so that foliage of nonflowering plants is not damaged.

Finally, to minimize any unforeseen negative effects of fire on the orchid population, the researchers strongly recommend that only a portion of the habitat be burned in any year. A safe option would be to divide the orchid habitat and burn only half or less. In the future, when managers at Pipestone National Monument must make decisions about burning in this remnant tallgrass prairie, they will know that they need to consider not just the current weather but also that of the past and future. ■

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(*Pinus rigida*), white oak (*Quercus alba*), and black oak (*Quercus velutina*). They also found that nitrogen levels are significantly higher under locust than under native forest approximately 66 feet (20 m) away from the locust stand.

Total land cover of black locust in the outer Cape has significantly declined over the past three decades, as revealed by historical aerial photographs. Stands that were formerly locust are currently intermediate between native pine-oak and nonnative locust stands in levels of ammonium and nitrate, and also intermediate in nonnative species richness. Preliminary results from a greenhouse study conducted in spring 2005 indicate that the nonnative understory plant species Kentucky bluegrass (*Poa pratensis*) and bouncing bet (*Saponaria officinalis*) had significantly greater growth in soils collected from under black locust and former

Understanding that native forests are associated with lower levels of nonnative plants means that … letting the process of natural succession continue [from invasive black locust] to native pitch pine and oak is the best control.

locust stands than in soils collected from native pine and oak forests or sand, which served as a control. Thus the introduction of a novel functional type (nitrogen-fixing tree) into this sandy, nutrient-poor, upland forested ecosystem resulted in "islands of invasion" within this otherwise invasion-resistant system.

These research findings are relevant to park management when prioritizing activities to control invasive plants. Understanding that native forests are associated with lower levels of nonnative plants means that, where black locust occurs in areas that are reforesting, letting the process of natural succession continue to native pitch pine and oak is the best control.

Chief of Natural Resources at Cape Cod National Seashore Nancy Finley found this information very useful. She says, "This study saved the park from initiating efforts not only to control black locust stands … but also to control the heavily invasive-infested understory within those locust stands.… In time, both the locust and its exotic community will decline without any park intervention … allowing us to focus on more imminent problem sites." Given the mosaic landscape of Cape Cod and many other national parks, understanding the susceptibility of habitat types to invasion of exotic plants is a necessary tool to manage the landscape for the highest native biodiversity. ■

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BLACK LOCUST LAND COVER, SALT POND, CAPE COD NATIONAL SEASHORE

Investigators in the black locust study analyzed aerial photography of Cape Cod National Seashore (Salt Pond area shown here), identifying a significant decline in the extent of the invasive tree species from 1970 to 2002. Though they encourage growth of nonnative plants, nitrogen-fixing black locusts eventually give way to native pine and oaks and understory native plants.